A MASS MEMORY UNIT FOR THE SPACE SHUTTLE ORBITER

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Summary. A high-capacity, medium access time data storage system has been developed to interface with the five General Purpose Computers (GPC) in the Space Shuttle System. Termed a Mass Memory Unit (MMU), this system uses magnetic tape as the storage medium.

There are two basic functions for the MMU in the Space Shuttle System. First, the MMU will be used to provide display format storage. These displays will be used for vehicle operational procedures and on-line status. The second function is as an auxiliary memory to be used to store and load/reload all phases of flight/ground software.

The stored data is catalogued by using eight longitudinal channels (tracks) and eight transverse channels (files). Each file is divided into eight subfiles, and each subfile is divided into 32 blocks. Any one or more blocks or any subfile can be addressed by the GPC.

The MMU is capable of storing 1.31 X 10^8 bits and has a nominal access time (to the nearest block of data) of 600 milliseconds. The data transfer rate is 1 X 10^6 bits per second and recording is at a packing density of 5 X 10^3 bits per inch.

The MMU is a hermetically sealed unit which occupies approximately 1,000 cubic inches and weighs approximately 25 pounds. The wear-related items have been designed to ensure over 20,000 tape passes without maintenance.

As an advanced form of data storage, the MMU fills a void between slow-access tape drives of high-storage capacity and disks or drums with fast access time and relatively low-storage capacity. In contrast with disk or drum memories, the MMU consumes operating power only when active, which yields a very low average mission power.

Introduction. Because of the unique requirements presented by the Space Shuttle system (7-day missions), it was deemed necessary to develop a new type of data storage system. This system had to have a low average power per mission with high-data storage capacity and medium-fast access times.

The previous answer to similar requirements in the military aircraft field was to choose either an IBM compatible 800 bpi closed-loop tape transport, or a drum or disk system. The basic problem with the 800 bpi tape transport for the Shuttle is its high-running power (approximately 1,000 watts). The basic problems with a disk or drum system are its low-data storage (approximately 10^6 bits) and high average power (60 - 80 watts).

The Mass Memory Unit was then developed to fill the gap between these two choices.

Text. The Mass Memory Unit (MMU) is a magnetic tape record/reproduce device with a storage capacity of approximately 1.31 X 10^8 bits of digital data. The MMU interfaces with a General Purpose Computer (GPC) by means of a bidirectional 1 MHz Data Bus.

The MMU provides for the nonvolatile storage of large volumes of digital data. The MMU can be viewed as an extension of the GPC memory. Each of several GPC’s can access this data by “reading” data blocks through serial commands to the MMU. Each GPC can also store data blocks in the MMU.

The MMU is specifically intended for spacecraft operation. The tape transport mechanism is internally mounted on vibration isolators to protect critical precision elements during the launch environment. The enclosure is hermetically sealed and pressurized slightly above the normal sea-level atmosphere.

Three connectors (J1, J2 and J3) are on the front cover of the MMU. Twenty-eight volt DC power, power return and chassis ground are connected to the MMU at J1. The input/output signals and certain test signals are connected at J2. J3 permits the use of Ground Support Equipment for the purpose of formatting the tape, verifying MMU performance, and analyzing various internally generated MMU signals.

The normal operating power used by the MMU is substantially reduced during inactive periods. When data reading or writing is not required, the MMU reverts to a STANDBY mode in which only those logic functions necessary for GPC interface are enabled. The average power of the MMU is 21 watts.

The GPC controls the MMU with specially coded commands. If not busy (if READY), the MMU responds to these commands by performing the requested action, by transmitting data, or by transmitting information. When writing or reading digital data, the GPC command includes an address which identifies the location at which the data is to be written on or read from the MMU tape. The location is identified by Track, Subfile, and Block. In all, 2,048 unique block addresses are available on each of the eight files. Each block contains 512 16-data-bit (plus one parity bit) words. Data location on the tape is discussed in detail in a later paragraph.

The pertinent MMU specifications are summarized in Table I.

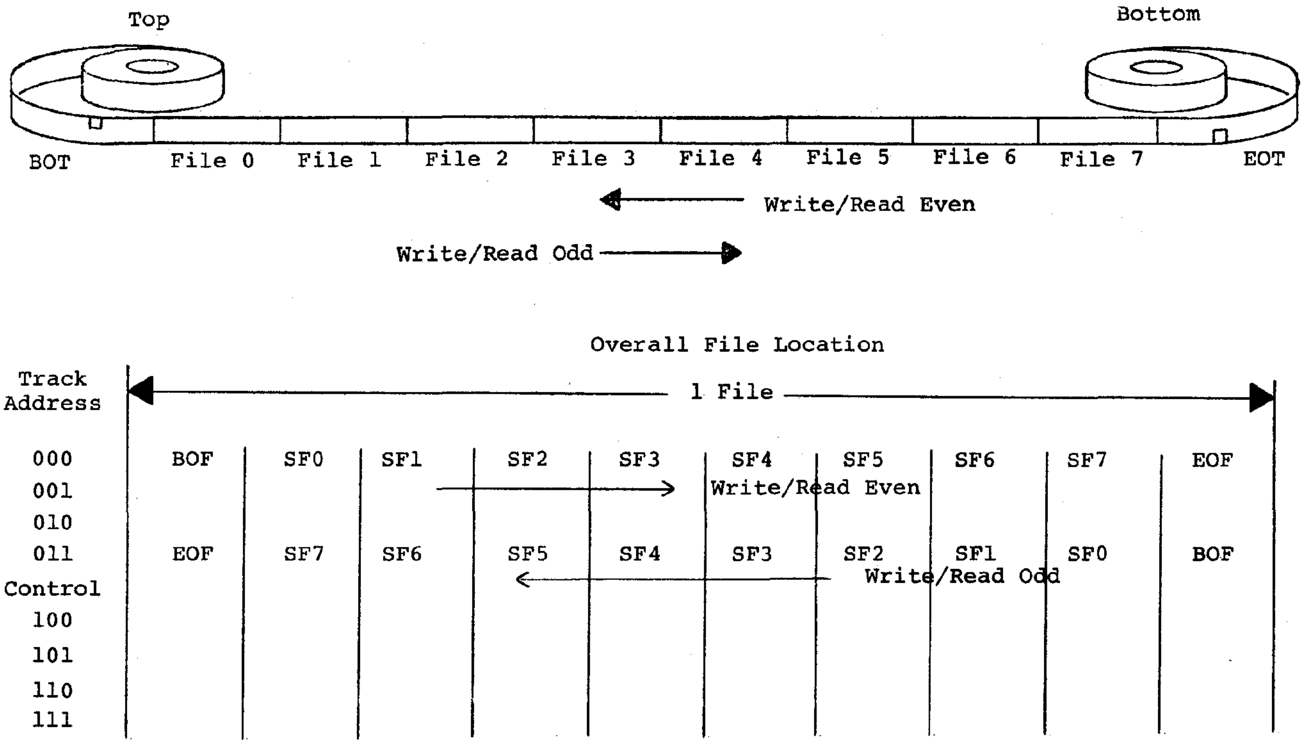
Table I
MMU Specifications

Size	11.6 inches wide x 15 inches long x 7.5 inches high (outline dimensions)
Temperature	-20°F to +120°F (ambient); when secured to cold plate (+35°F to +120°F)
Data I/O Rate	33.5 ±0.5 microseconds/word
Word Length	17 bits (including parity bit)
Error Rate	Errorless in 1.31×10^8 bits
Write Enable	Selective enabling of any or all tracks is controlled at MMU connector J3
Access Time	$\leq$ .70 sec
Traverse Time	One subfile traversed in 0.549 sec
Tape Speed	100 ips

The storage medium used in the Mass Memory Unit is 602 feet of magnetic tape. As seen in Figures 1 and 2, the tape is broken down as follows:

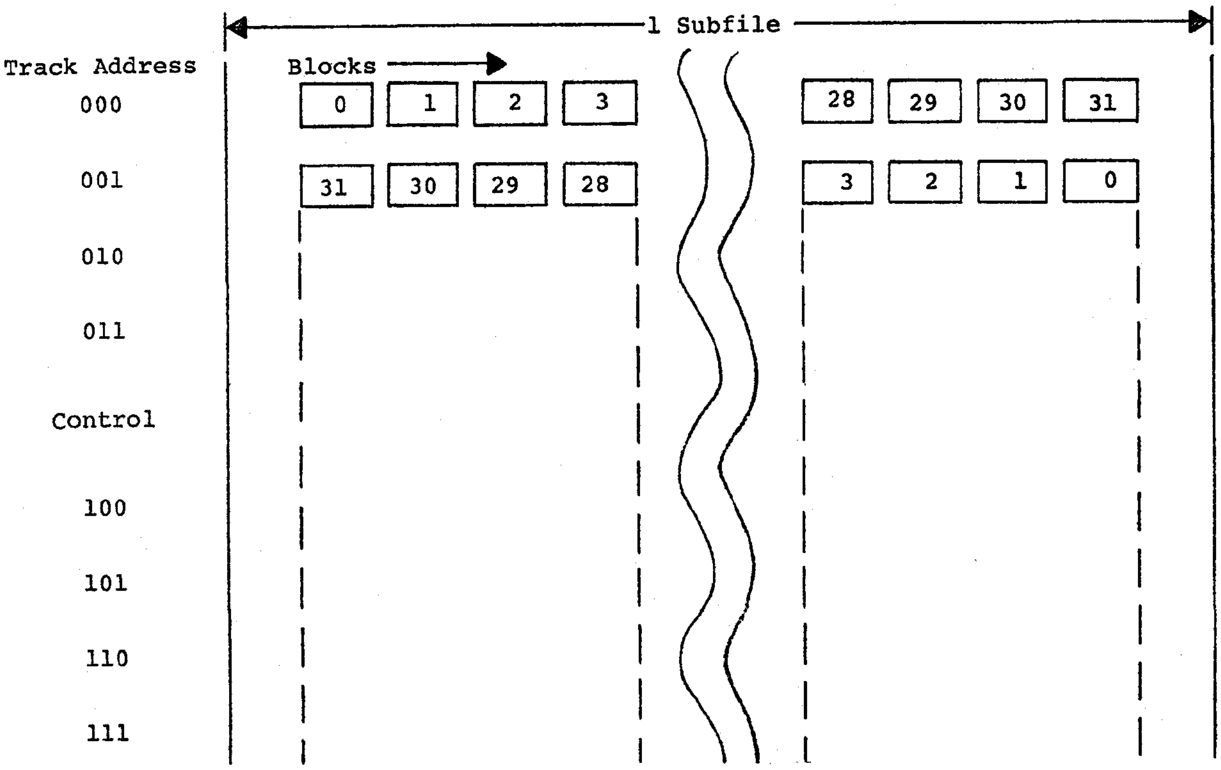
The bulk of the tape is used by the eight files (numbered 0 - 7). Each file contains eight tracks (0 - 7) of data broken up into eight subfiles (0 - 7). It should be noted that although these subfiles are numbered from 0 to 7 in the forward direction (even tracks), these same subfiles are also numbered 0 to 7 in the reverse direction (odd tracks). This was done to facilitate the computer software development. Also, there is a beginning-of-file area, an end-of-file area, and a control track located within each file. The beginning-of-file and end-of-file areas are only used for starting and stopping. The control track is a very important and unique element of the MMU. It provides the necessary information to allow the location of the needed data. The control track will be discussed in greater detail later.

Each subfile is broken up into 32 blocks (0 - 31). Each block contains 512 data words. Each word contains 17 bits—16 data bits and one parity bit.



MMU File Organization

Figure 1



MMU File Organization

Figure 2

Although only 17 bits are written on the tape for each word recorded, 28 bits are sent by the GPC to the MMU, and 28 bits are sent by the MMU to the GPC. The 28 bits are structured as follows:

Bits 1 - 3 are used by the MMU or GPC to decide if the rest of the word represents a command word or a data word.

Bits 4 - 8 are decoded to determine if the message sent by the GPC is meant for that particular MMU, or if sent by the MMU, they tell the GPC from which MMU the message is coming.

Bits 9 - 24 are the 16-data bits to be written on tape.

Bit 25 is the power transients bit and is set to zero if a power transient occurs.

Bit 26 is always a zero.

Bit 27 is the Validity bit and is set to zero to indicate an error condition occurred.

Bit 28 is the odd-parity bit.

Bits 9 - 24 are written on the tape along with a new odd-parity bit based on just bits 9 - 24. Bits 1 - 8 and 25 - 28 are discarded as overhead.

Modes of Operation. Now that we have discussed how the MMU data is formatted on the tape, let us now see what functions can be performed by the MMU. There are five basic operations that the computer can request that the MMU perform:

1. Position tape.
2. Write new data on the tape.
3. Read previously written data from the tape.
4. Transmit the status registers.
5. Transmit tape position data.

These (and all other) commands will be accepted by the MMU only if the MMU is READY (not already performing an operation).

The position tape command is the only command that allows the tape to be moved from one file to another. All other commands are operated on within the file in which the MMU has stopped. In addition, the position tape command can also be used to position to a different file gap or subfile within the file in which the MMU has stopped.

The write data command allows the GPC to write new data in any location within the file in which the MMU has stopped. Since data is written in the forward direction on tracks 0, 2, 4, and 6 and in the reverse direction on tracks 1, 3, 5, and 7, care must be taken to position the tape at the proper place. For example, if it is desired to write this new data on track 4 in subfile 6, the MMU must be positioned on the beginning-of-file side of subfile 6 so that the MMU will be moving in the forward direction when it comes to subfile 6. Likewise, if it is desired to write the data on track 3 in subfile 6, the MMU must be positioned on the end-of-file side of subfile 6. If the MMU is requested to read data that is “behind” where it is positioned or within the subfile in which it has stopped, the MMU will take no action and an error indication will be set. For example, if the MMU is directed to write data in subfile 4 on track 6 and the MMU is positioned to subfile 5 on track 6 it cannot read subfile 4 while moving in the forward direction (as required by calling for track 6). Therefore, no action will be taken and an error indication wil be set in the status register.

The sequence of events that is necessary in order to write new data is as follows:

1. The MMU must be properly positioned as discussed above.

2. The track on which data is to be written must be one that is enabled by a hardware enable located on connector J3.

3. The write command must be preceded by a write enable command.

4. The previously written data must first be erased before the new data can be written.

Items 2. and 3. comprise the system that safeguards critical data that has been previously written and is to be retained. If this data is written on track 2, for example, and track 2 is disabled, then new data cannot be written on track 2. If track 2 is mistakenly enabled, Item 3. requires that a write enable command that calls for track 2 be sent before the MMU will accept a write command. Thus, there is a double safeguard for that critical data.

When it is required to write new data and Items 1., 2., and 3., have been met, the old data must be erased before the new data can be written. Only the old data that is going to be rewritten must be erased (not any additional data). In order to do this erasing and rewriting in one pass, the erasing is done immediately before the data is written. A complex sensing and timing circuit senses when the erase should begin, the write should begin, the erase should end, and when the write should end.

The command to read previously recorded data works exactly like the write command as regards to proper positioning of the MMU prior to reading. The data can be read only in the direction in which it was recorded so care must be taken to position the MMU properly. If the MMU is requested to read data that is “behind” it or within the subfile in which it has stopped, no action will be taken and an error indication will be set. Since the reading of the data does not destroy the data, there are no restrictions on which tracks can be read. A read command tells the MMU which track, subfile, and blocks are to be read.

When either writing or reading data, only one track can be written or read with one command. Also, only 256 blocks of data can be written or read with one command. At 32 blocks per subfile and eight subfiles per track, these 256 blocks constitute all the data on any one track within a file (and are equivalent to one computer memory load).

The transmit status command requests the MMU to transmit the contents of the two status registers in the MMU. These status registers give a summary of any MMU error conditions.

The transmit tape location command requests that the MMU transmit its location to the GPC. The location is given in terms of track, file, and subfile (or file gap).

In order to provide a description of the MMU/General Purpose Computer interface when the above commands are issued, Table II has been provided. Table II shows the General Purpose Computer commands that are issued, any response by the MMU across the data bus, and any other action taken.

A functional block diagram of the MMU is shown in Figure 3. The MMU is divided into five functional areas:

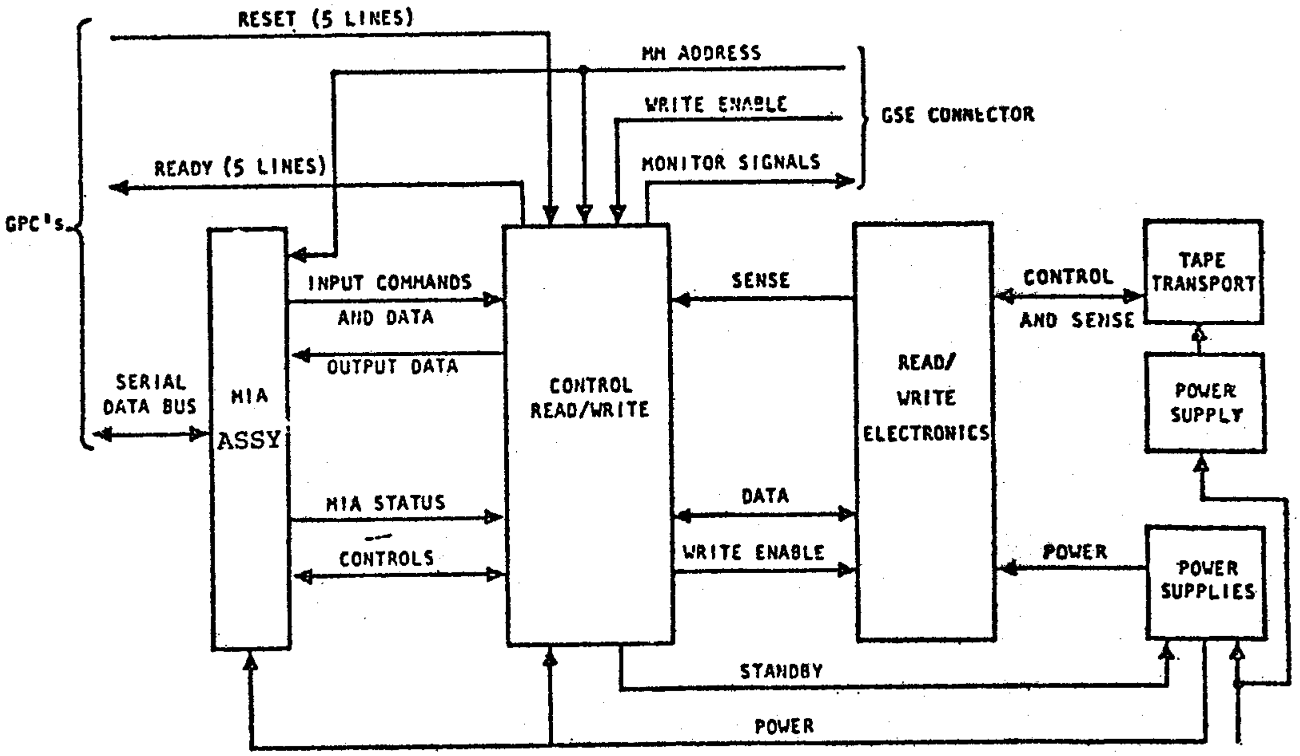
1. The Multiplex Interface Adapter assembly
2. The MMU control/read/write
3. The read/write electronics
4. The tape transport
5. The power supplies

A more complete description of these blocks follows.

Table II

GPC Command	MMU Response	Action
Position Tape	-	Moves tape within MMU to requested file and subfile location
Write Enable	-	Enables subsequent write command (on hard-wire enabled tracks).
Write	-	Commands MMU to accept forthcoming data words. Describes subfile, block, and track location.
	SCW	The search complete word is issued by the MMU 32 word times before actual writing of a data block begins. Upon each issue, the GPC should begin transmitting 512 sequential data words per block.
Write Data	-	GPC transmits 512 data words per block.
Read Status	-	Requests status report of any problems detected within MMU.
	Status	Reports Registers A and B status. Resets any error bits in status register.
Read Command	Data Transmission	MMU starts reading at selected track, subfile and block and continues reading up to 16 blocks. Status (error) data is transmitted with each word.
Extend Block Count	-	Selects a sequential number of blocks (no more than 256) within a single file and track for a subsequent write or read command.
Read Command	Data Transmission	MMU starts reading at selected tracks, subfile, and block. Continues reading block until the requested extended block count is satisfied.

GPC Command	MMU Response	Action
Read Status	-	Provides status report of any problems detected at MMU since last status request. Resets any error bits in status register.
Position Request	-	Provides positional report of current MMU location by file, subfile/gap, and track.



Mass Memory Functional Block Diagram
Figure 3

Multiplex Interface Adapter Assembly. The Multiplex Interface Adapter assembly is the interface between the MMU and the data bus and provides formatting and synchronization for all data transfers. It also decodes all messages sent on the data bus and accepts only those meant for that particular MMU.

Control/Read/Write. The functional block labeled Control/Read/Write (CRW) is the control center for the operation of the entire MMU. The CRW accepts incoming commands and data from the Multiplex Interface Adapter assembly. it then decodes the commands, establishes the proper operating mode and issues its own commands to the transport electronics. The CRW, after accepting the incoming data from the Multiplex Interface Adapter, buffers it in a Random Access Memory, then apportions it to the write electronics at the proper rate to be recorded. This same buffer is also used in the read mode to apportion the data to the Multiplex Interface Adapter. This buffer is necessary because the data is written and read at a rate of 17/28 X (1 MHz) or 607 KHz.

The CRW also provides the decision logic to determine (with information from the various error condition monitors) which status errors should be set. Further, the CRW controls some of the interfaces with other blocks. For example, the initial power-on timing sequence and the shutdown to standby are controlled by the CRW.

Read/Write Electronics. This functional area selects the designated read or write head, erases and records data on the tape, or reads data from the tape at locations designated by the control/read/write logic. Control track identification data is sensed to properly locate or record data on the data tracks for recordings in either the forward or reverse tape direction. Additionally, status signals indicating head-to-tape interface status are provided to the control/ read/write logic.

Tape Transport. The tape transport contains all power supplies, electronics and electromechanical devices necessary to (1) physically start, stop, and transport the tape at a constant tape speed during position, read, or write operations; (2) control tape tension and reeling; (3) optically sense the beginning and end of tape; and (4) generate transport status to the control/read/write assembly.

Power Supplies. The power supplies convert orbiter primary power (23 - 32 VDC) into the various regulated voltage levels required by the MMU electronics and the servo. Power is constantly supplied to the Multiplex Interface Adapter assembly, but most of the MMU power supplies are switchable so that power can be removed from nonessential areas when the MMU is in the standby mode waiting for a command f rom the GPC.

Mass Memory Tape Control Track. The tape load is divided into eight files across eight tracks. The location of any data block is controlled by a ninth track (control track). This track is formatted prior to writing data on the data tracks. The recorded frequency of the control track bits is 29.85k bits per second and equals the frequency of the data track words. This results in one control track bit position for each data word (17 bits) on the tape.

The initial writing of the ninth track is performed in two passes. Starting at the optical BOT, all previously recorded data is erased with the lead erase/write head while the trailing write/erase head records the control track format for each data file until the EOT is reached.

Performance Monitoring. Certain of the internal MMU areas are monitored and provided externally for performance monitoring and evaluation of MMU operation.

The multiplexed output of internal power supply voltage monitors is provided for specific indications of each internal power supply. Each power supply output voltage is normalized to 2.5 volts and is then the input to a multiplexer, which outputs the normalized voltages in a predetermined sequence.

Internal temperature is monitored by a thermistor located near the read/write heads. This analog device is made available for external monitoring.

The internal pressure of the MMU is sensed by a solid-state pressure transducer, and the analog output is made available externally.

One of the most vulnerable points of wear or degradation occurs at the head-to-tape interface. An analog head-to-tape interface signal is generated by conditioning the signal level of the reproduce (read) head to a positive voltage proportional to the peak signal detected. This output is also made available externally.

Built-in Test Equipment. Built-in test equipment is incorporated within the MMU to detect error conditions which would affect normal operation. Error conditions detected during MMU operation set indicator bits in two status registers (A and B). The setting of an error status bit results in the Validity bit of the following response messages being set to zero. The General Purpose Computer, as a result of detecting the Validity error, ignores the response message. The General Purpose Computer may interrogate the MMU by issuing a “read status” command. The MMU responds to a “read status” command by transmitting the contents of both status registers to the General Purpose Computer. The Validity bit is forced to a true state in the response message by the General Purpose Computer. In addition, the “read status” command also resets both status registers. If the original error still exists, the status error bit will be set again and the Validity bit will be set to a false state.

Ground Support Equipment. The Ground Support Equipment that is used with the MMU is an automated test system. This test system consists of a mini-computer with l6k bytes of memory, a 28-volt power supply to power the MMU, a digital voltmeter, an input/output processor and a teletypewriter. The attendant software allows the user to completely test the MMU (with a functional test procedure) by typing in instructions to the test system through the teletype. The test system will apprise the user of the results of the tests and provide both success print-outs and failure printouts. The test system is also used to generate the control track. However, a clock signal is provided by the MMU to the test system during the writing of the control track so that control track timing is not dependent upon the internal clock of the test system (which would vary from test system to test system).

Conclusion. We have herein presented a portrait of a high-reliability, long-life data storage system. This unique system combines low average power, medium-speed access times, and high-data storage capacity to bridge the gap between disc/drum systems and high-power, low-access time tape transports. This system is presently being used on the Space Shuttle, and future applications include the European Spacelab.